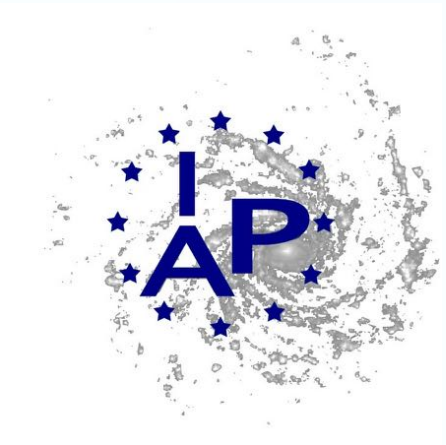
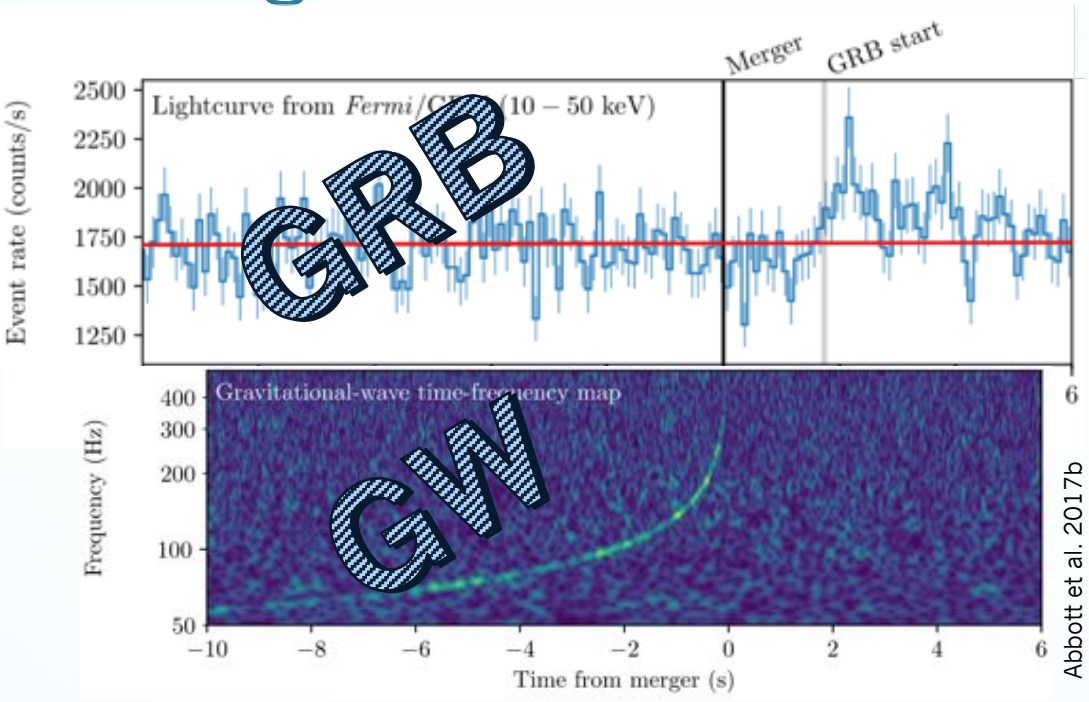


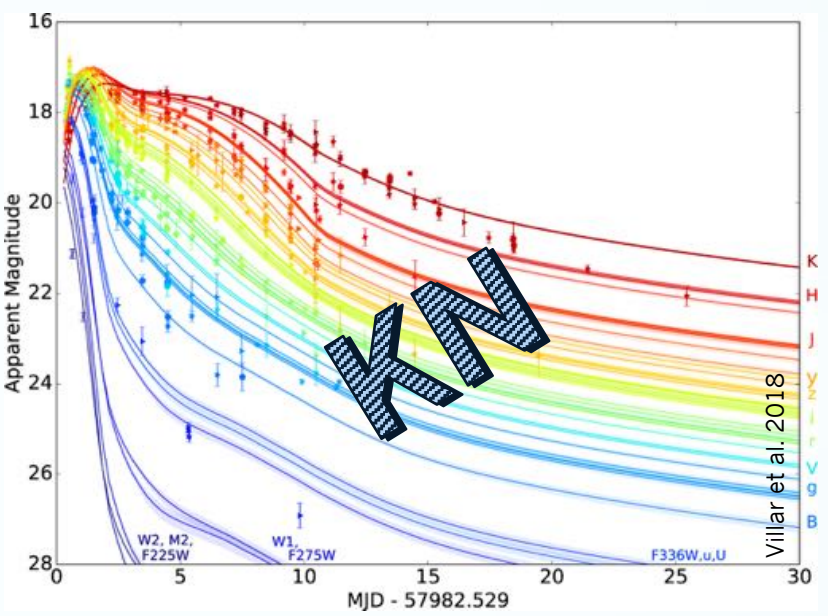
Population Prospects for Electromagnetic Counterparts to Binary Neutron Star Mergers

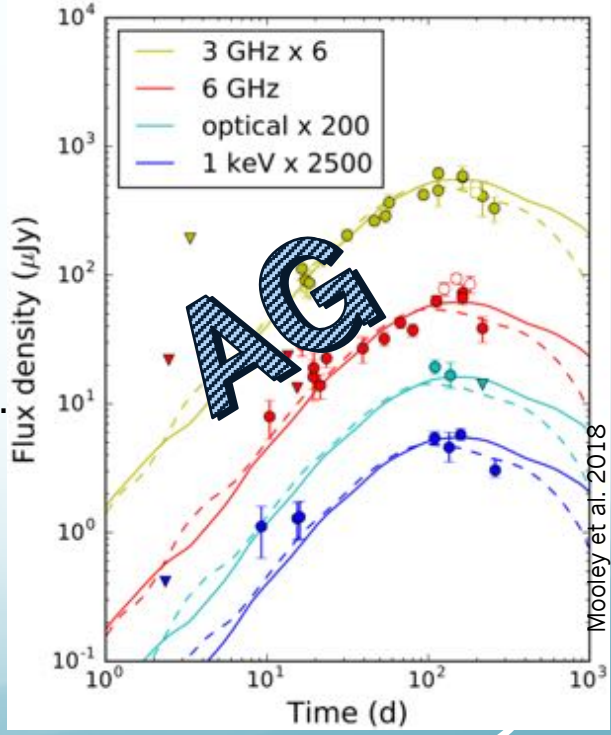
R. Duque, F. Daigne & R. Mochkovitch

Sept. 25th 2019 – Atelier TS2020

On August 17th 2017…





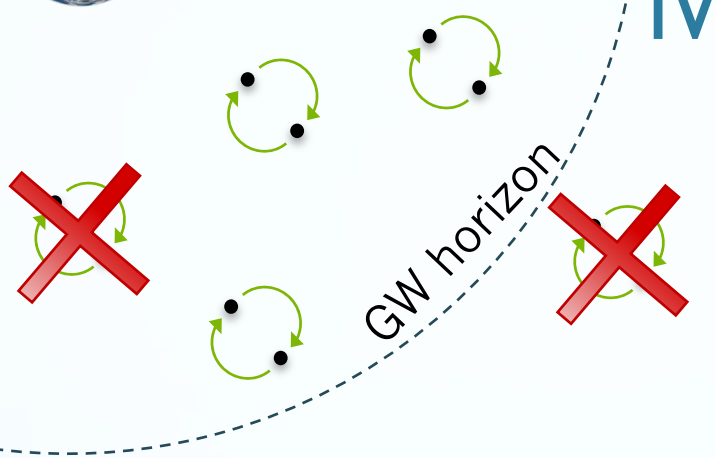


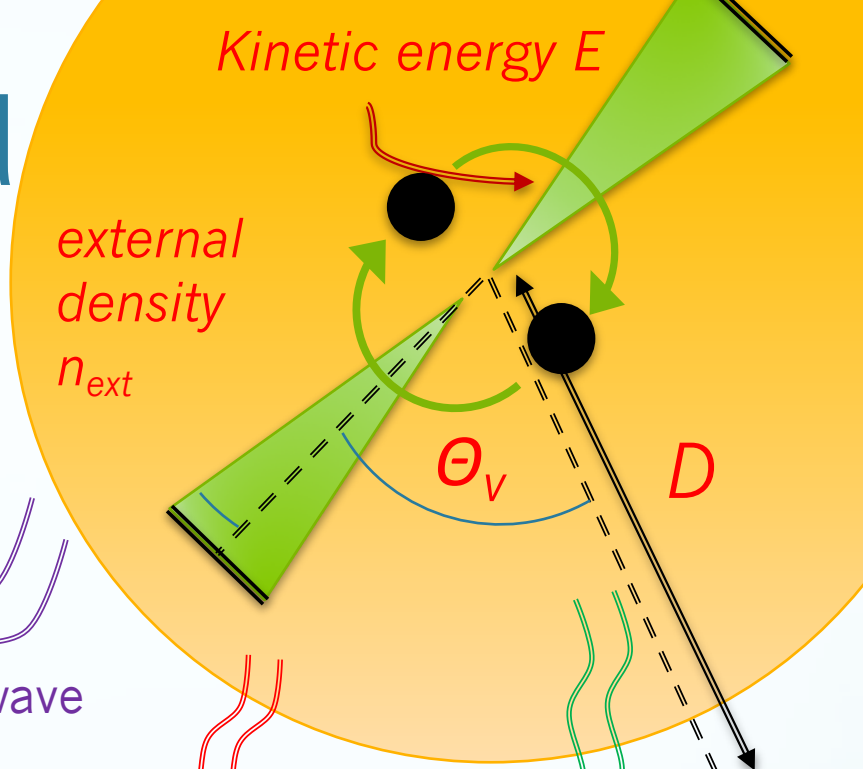
- Confirmed NS-NS mergers as **progenitors for short GRBs**
- Inauguration of the **era of multi-messenger astronomy with GW**
- Other fundamental (astro-)physics: GR, NS EOS, Hubble constant measurement, *r*-process nucleosynthesis, etc.

Afterglows and kilonovae: What should we expect for O3?

1540^{+3200}_{-1220} BNS/Gpc^3/yr (Abbott+2018)

Method





Gravitational wave

Multi-λ Afterglow

Kilonova

Signal depends on D, Θ_v

Signal depends on D, Θ_v, E, n_{ext}, ...

Signal depends on D, Θ_v

Population model from sGRB science + 170817 observations
+ **Detection criterion**
→ **GW+AG or GW+KN predictions**

GW+GRB: Beniamini+18

(Detectable) radio afterglow rates for NS-NS

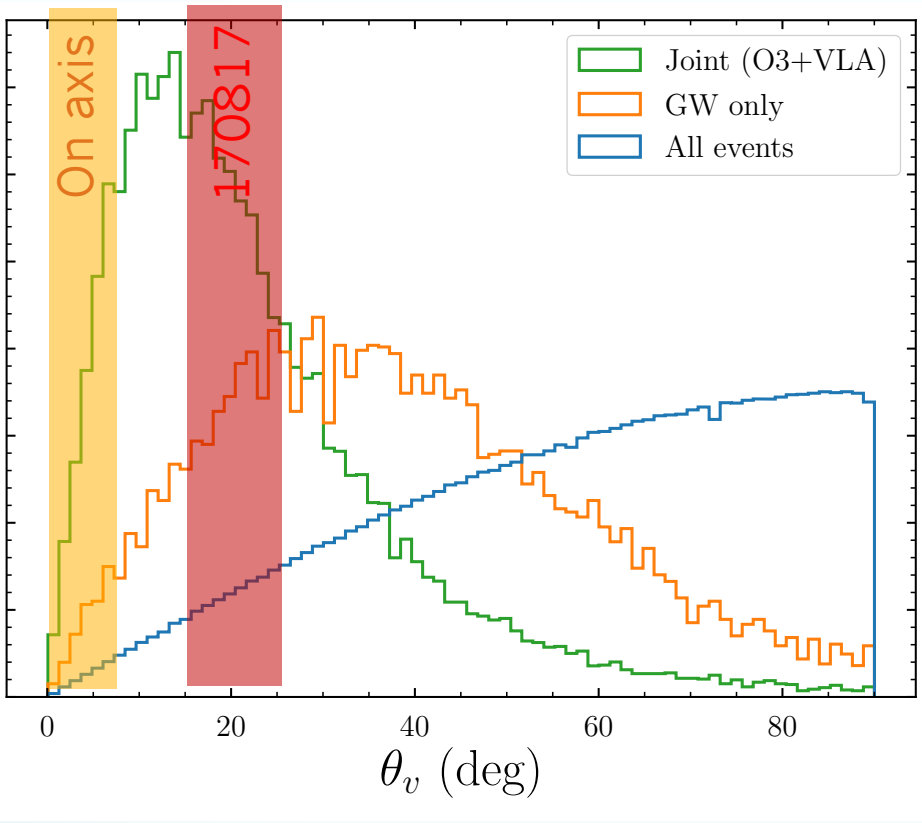
LVC Run	Radio Configuration		GW Events	Joint Events	Fraction of detectable events
	Instrument	s (μJy)	$N_{\rm GW}$	$N_{\rm joint}$	(assuming fiducial model)
O3	VLA	15	9^{+19}_{-7}	3^{+6}_{-2}	31.4%
Design	VLA	15	21^{+44}_{-16}	4^{+10}_{-4}	19.8%
Design	SKA1	3	21^{+44}_{-16}	7^{+18}_{-7}	34.7%
Design	SKA2/ngVLA	0.3	21^{+44}_{-16}	13^{+33}_{-13}	62.5%

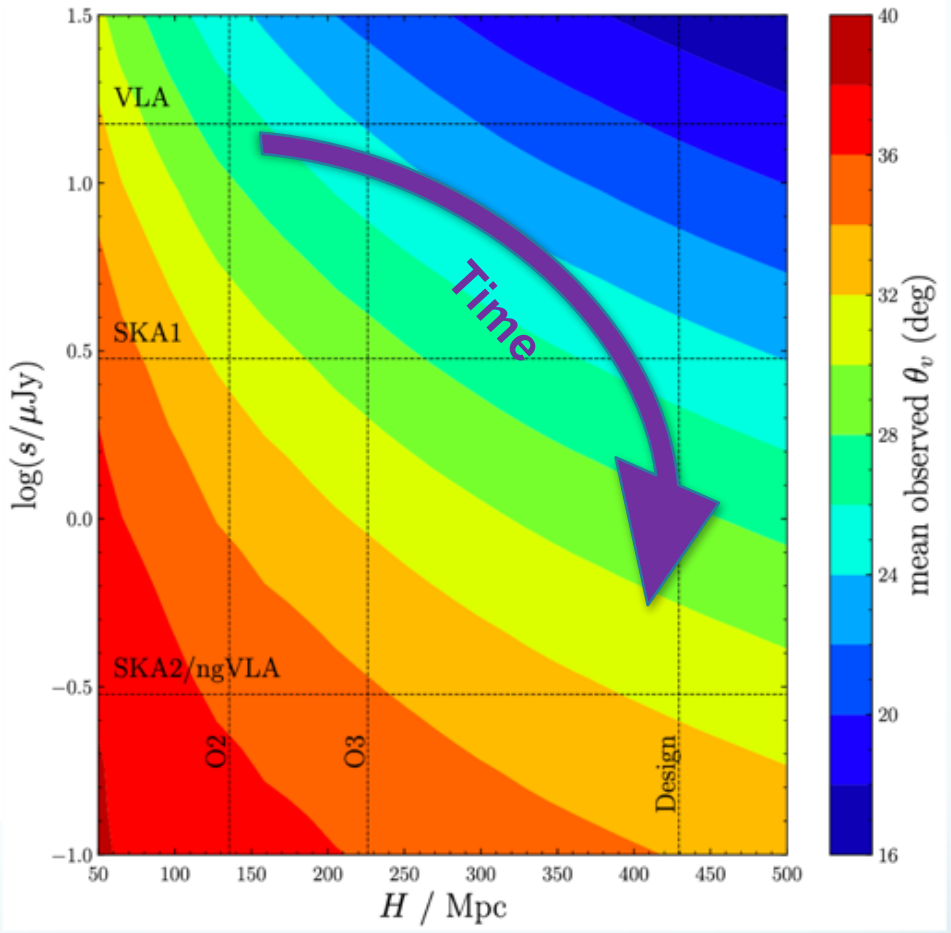
Can we **detect** the **detectable?**

Uncertainties: $^{+200\%}_{-73\%}$ (intrinsic rate from LIGO-Virgo O1/O2)
+ uncertainty on population model

- In general: **10-30% events have detectable AG** (depending on energy distribution)

Properties of joint events: viewing angle



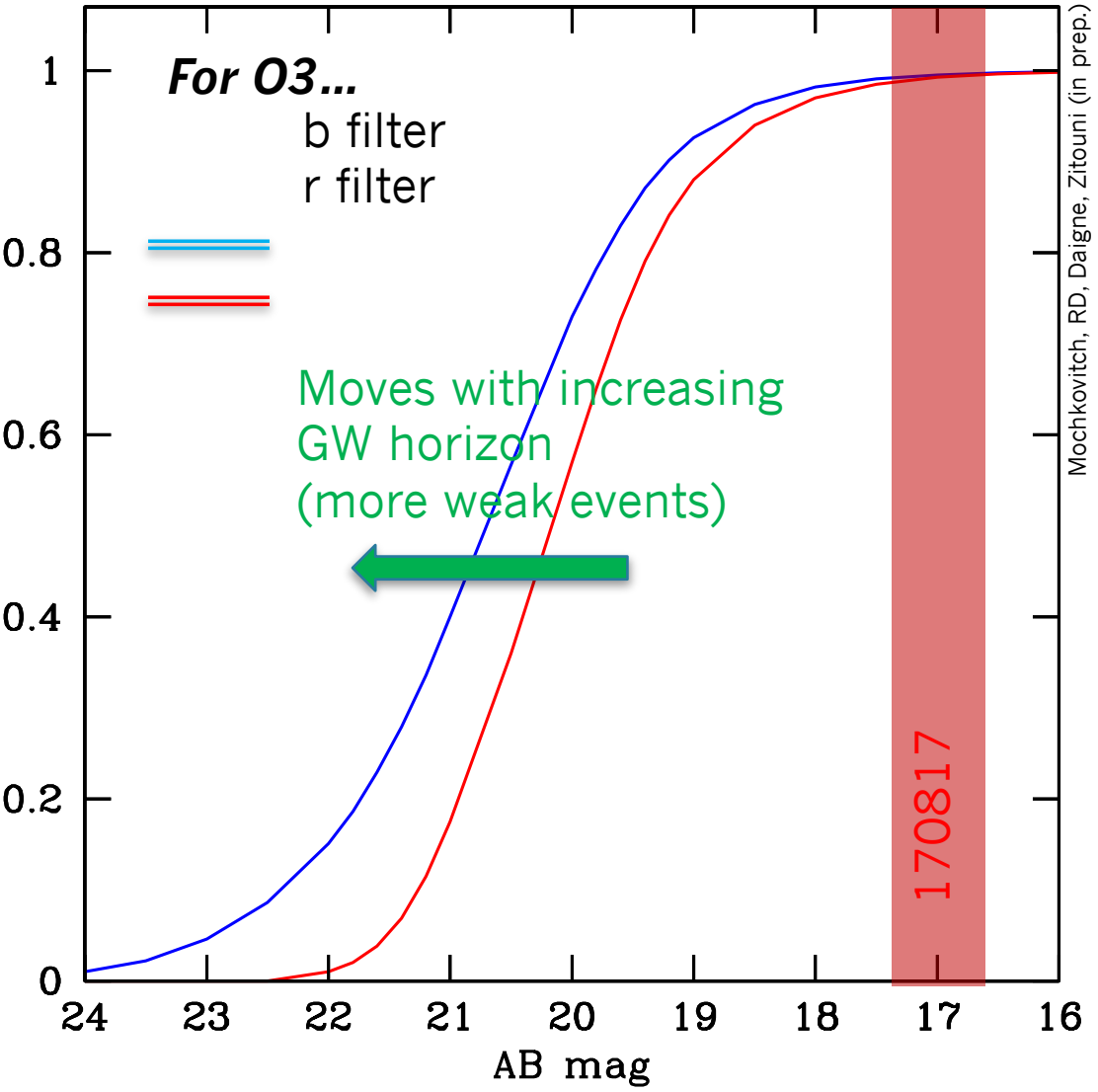


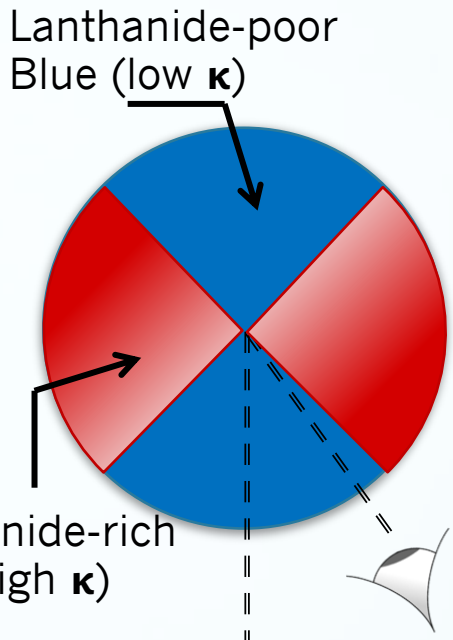
RD, Daigne, Mochkovitch 2019

- Most off-axis (mean angle ~ 20-30°)
- ≲10% **on axis "classical" GRB!**

GW+GRB ~ 1-10% (O3)
(Beniamini et al. 2018)

Expectations for kilonovae **(necessary for follow-up!)**





We include dependence of Vis.-IR signal on the **viewing angle** (Wollaeger+18)

For O3:

✓ **Magnitude OK** *a priori*

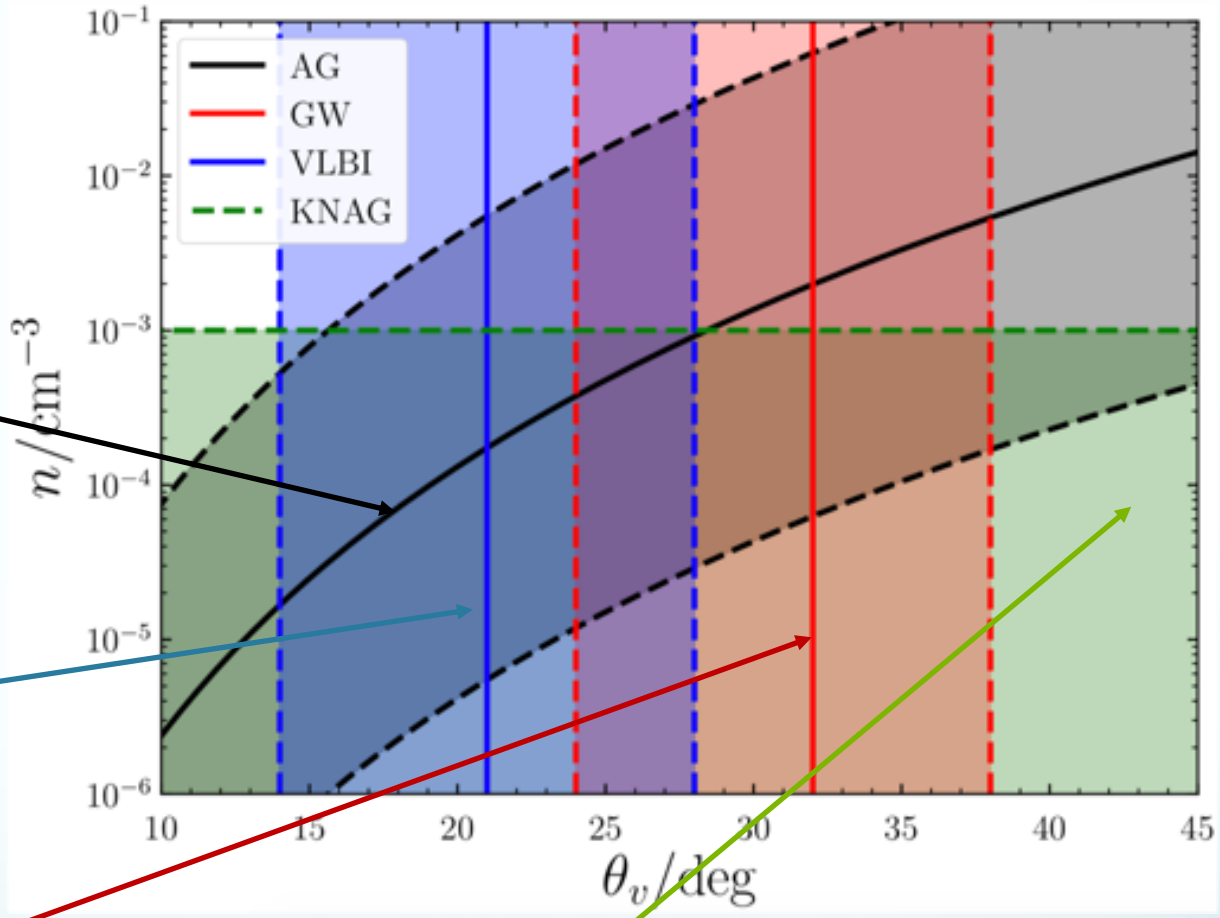
✗ Volume to explore potentially **100x larger** than for 170817

✗ Contrast with host galaxy

→ Finding the OT challenging (cf. O3)
→ Need for efficient wide-angle follow-up/surveys (LSST, etc.)

What are the minimal MM constraints?

For GRB170817A:



3 GHz afterglow (**using only peak properties!**)

VLBI measurement (**difficult in future**)

GW using event localization

Kilonova (slow, stratified) ejecta afterglow

Beniamini, RD, Mochkovitch, Daigne (in prep.)

→ Some robust constraints on viewing angle and density obtained without well-sampled AG

Fast-merging binaries

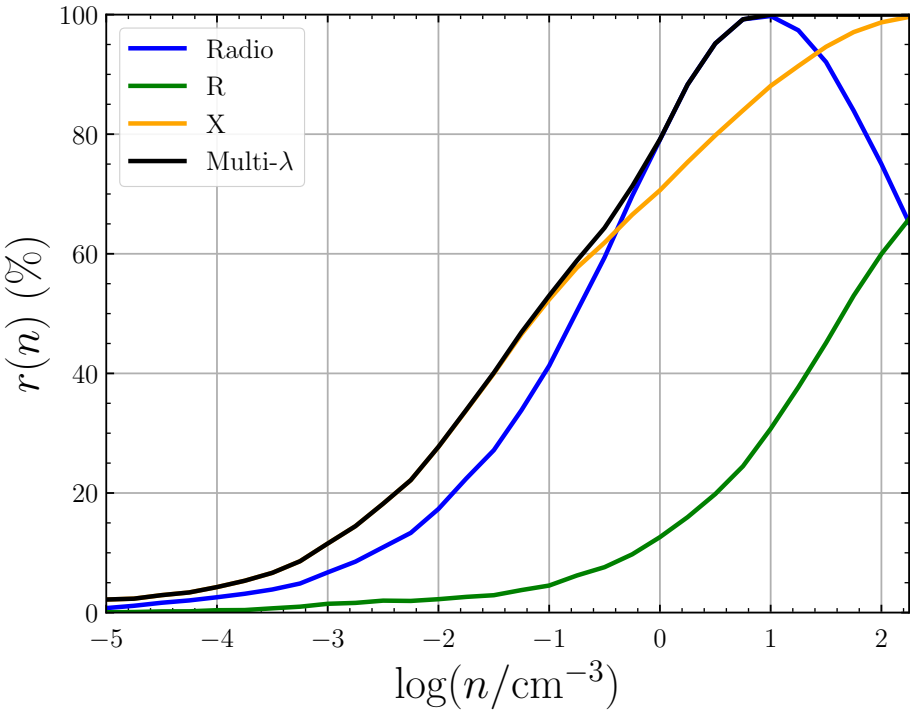
- **Debate on fast-merging binaries** (*r*-process element abundance, sGRB rate vs. cosmic SFR, Galactic binary population, etc.)

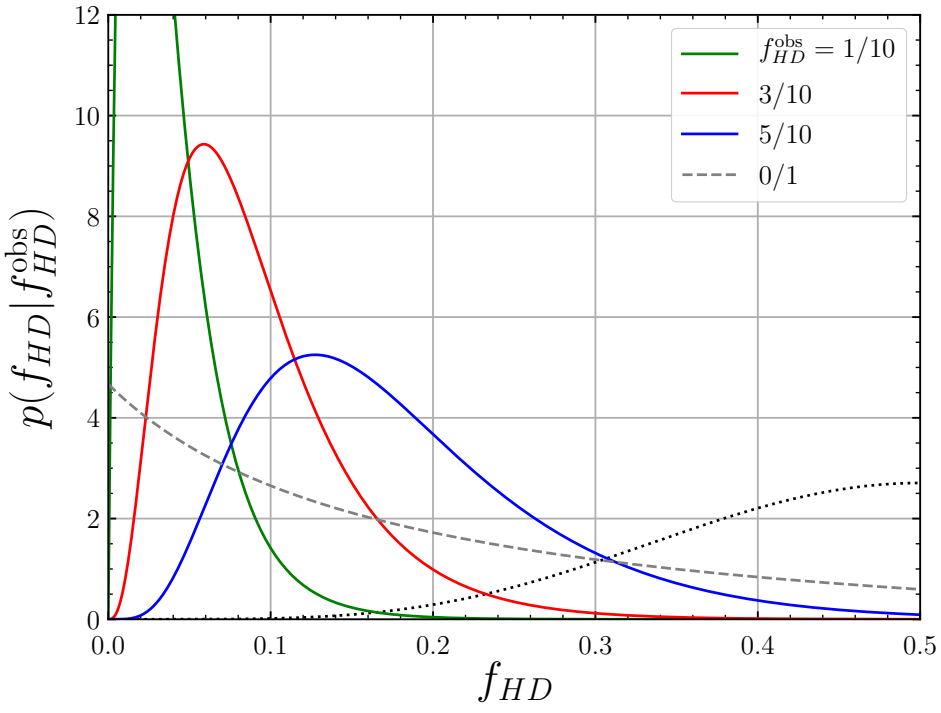
Formation medium density (high)

?

Merger medium density (low)

Fast merger → high density → bright afterglow ($F \sim n^{4/5}$)
→ **more likely detected → "magnifying glass" effect**

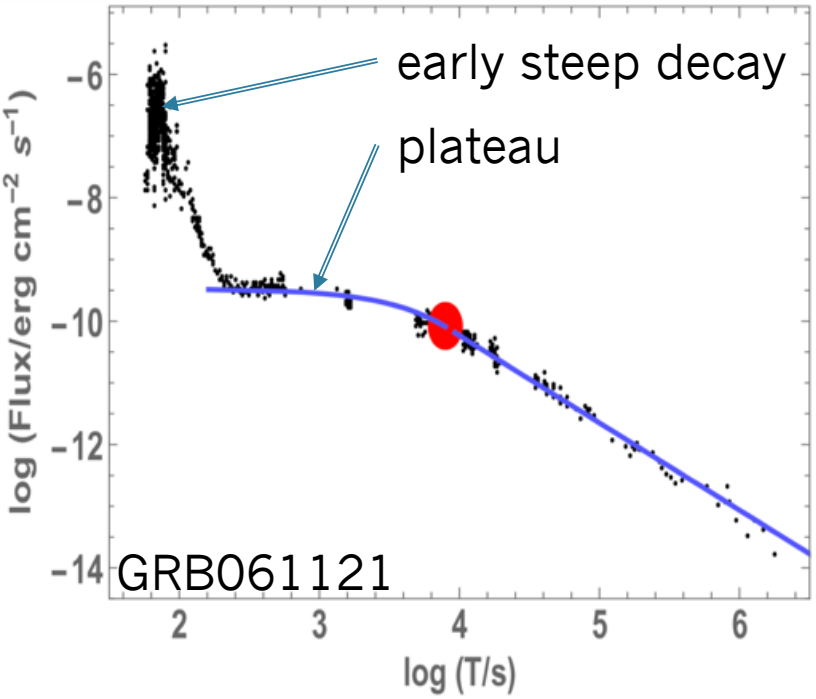




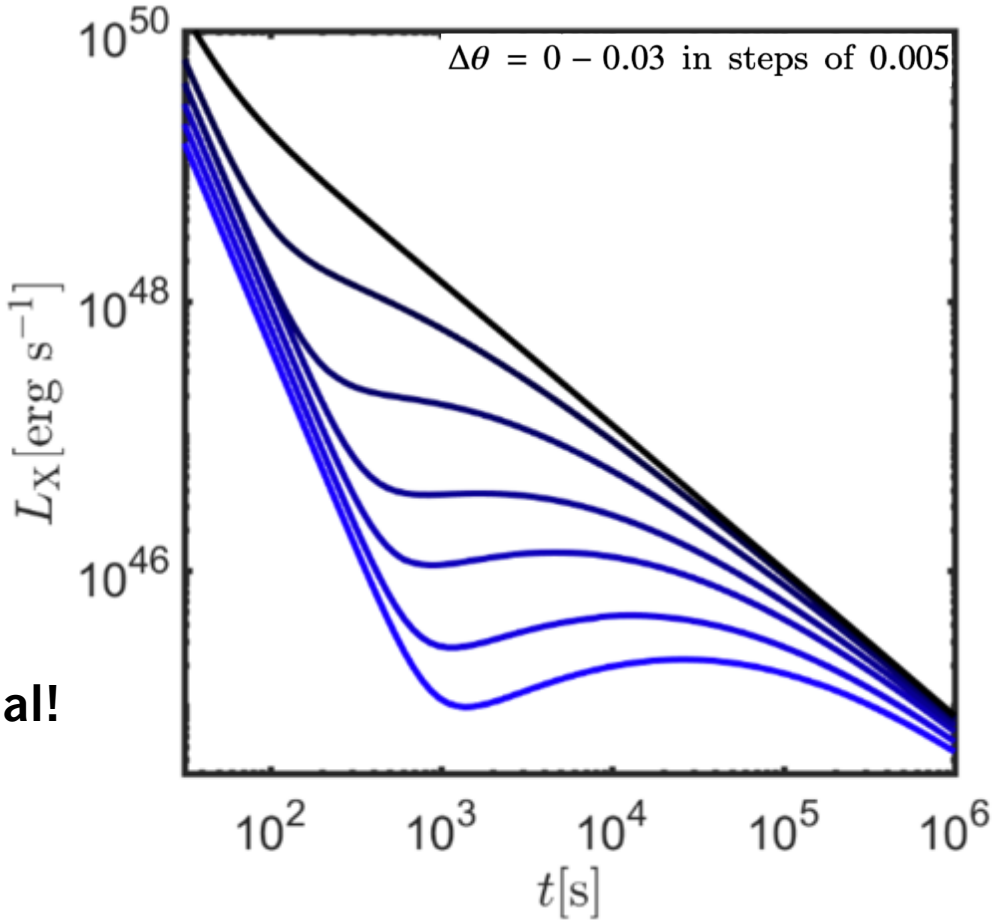
Benjamini, RD, Mochkovitch, Daigne (in prep.)

→ **Strong, direct constraints on high-density mergers with few events**

X-ray afterglow plateaux

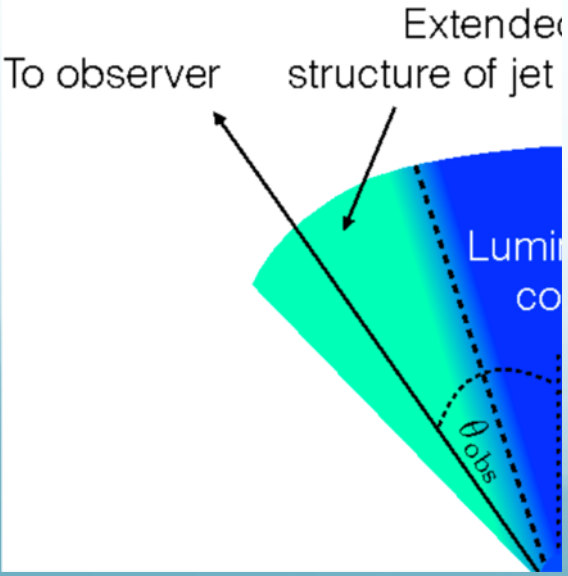


Dainotti+16



Beniamini, RD, Mochkovitch, Daigne 2019

AG from de-boosted energetic material!



Kathirgamaraju+18

$E_{\rm kin,iso} = 10^{54}$ erg, $\theta_j = 0.1$, $\Gamma_j = 400$, $\eta_\gamma = 0.1$,
$\epsilon_e = 0.1$, $\epsilon_B = 0.01$, $p = 2.2$ $\alpha = 8$, $\beta \gg 1$

→ Sensitive bridge between jet structure/viewing angle/afterglow
→ Observational perpsective with GW+AG events

Conclusion

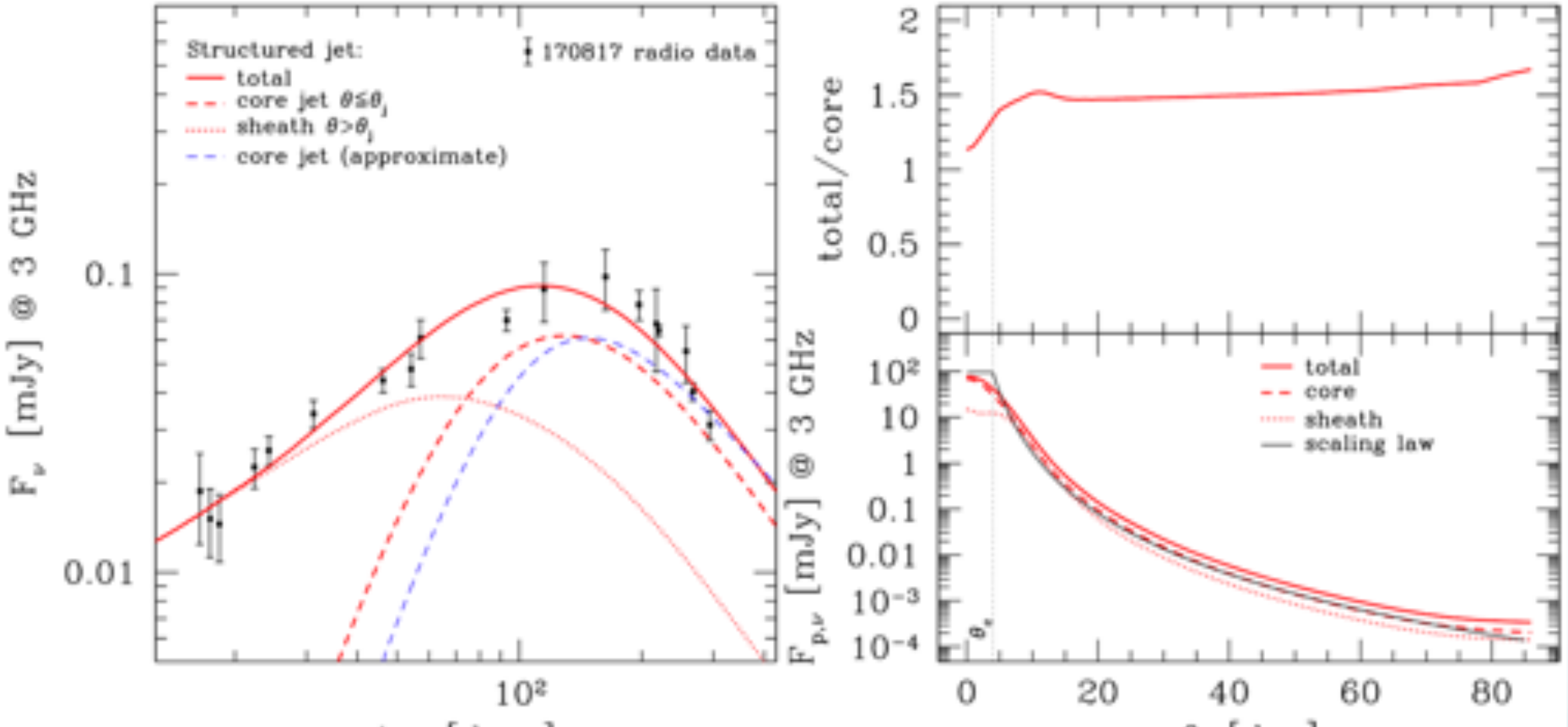
- At mid-O3: **several** BNS events still expected, **a few** with ***detectable*** afterglow, **all with *detectable* KN**

- ***Detectable*** is not ***detected!***
  1. Difficulty to find KN during O3…
  2. Increasing difficulty of VLBI imagery (flux and apparent motion) with distance

- Future events should be seen **off-axis**

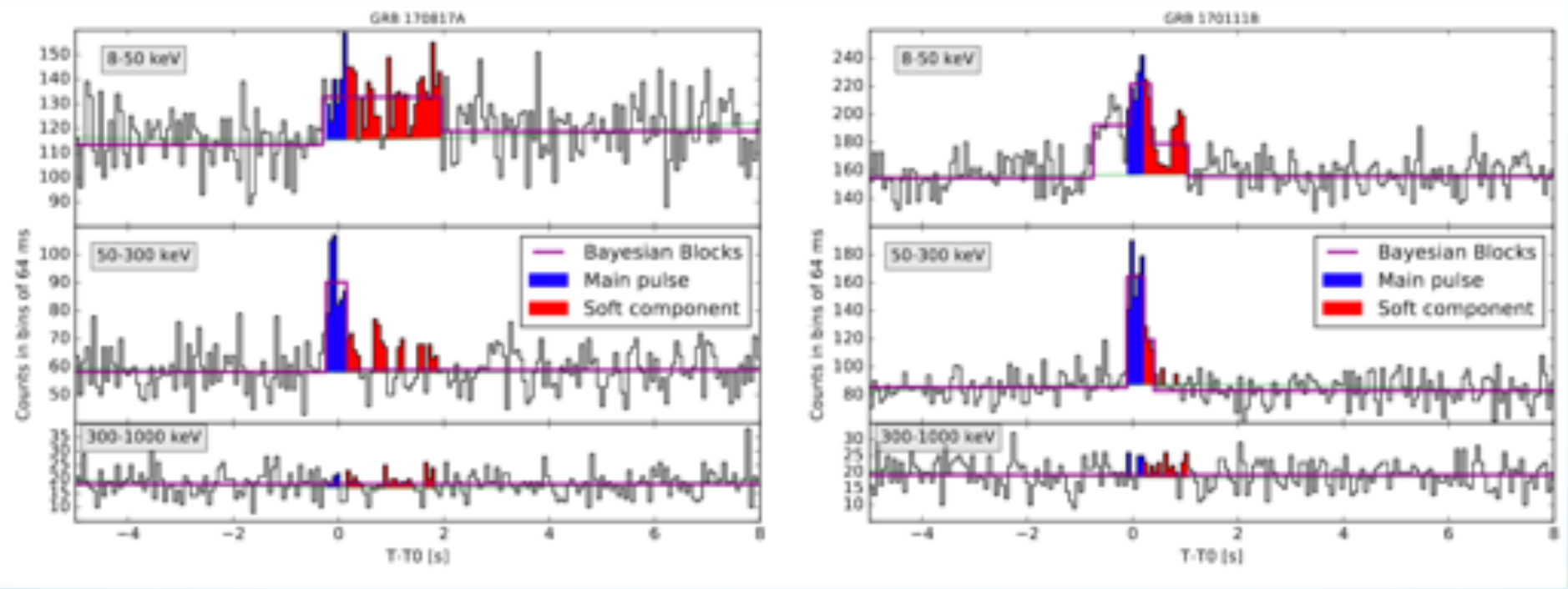
- Still can obtain some **mild constraints** on density and viewing angle and advance GRB science:
  - High-density mergers
  - Plateaux and jet structure
  - More!

Complete afterglow modelling



RD, Daigne, Mochkovitch 2019

Von Kienlin GRBs



Von Kienlin+2019